

Use of asphalt roofing shingle waste in HMA

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Abstract

Like other construction materials, shingles have their own service life based on raw materials, production method and environmental and climatic conditions. At the end of their service life, shingles need to be replaced. However, these old shingles together with manufacturing scrap and handling waste require large storage areas and pollute the environment in time. Hence, additional usage of shingle waste is desirable. In this study, shingle waste in amounts of 1%, 2%, 3%, 4% and 5% by weight was added as an additive to asphalt concrete mixes prepared with the optimum binder content which yielded the best stability value was 5%. After determination of the optimum percentage of shingle to be added, rutting tests were performed on the specimens. Taking into account, the binder content existing in the shingle, mixtures were prepared with the reduced binder content by 0.5% and 1.0%. Test results show that waste shingles can be used in HMA as an additive to improve the Marshall stability and rutting resistance of the mixtures.

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1. Introduction

The rise in the standard of living and the social and economic development over the last three decades has increased the demand for road usage, for safe and comfortable pavements in many countries. It is obvious that this demand can only be satisfied with pavement design procedures that result in pavements resistant to deformations, with longer service life and with satisfactory surface characteristics.

The commonly encountered distresses such as rutting, fatigue and low temperature cracking due to increase in axle loads, traffic volume, environmental conditions and construction and design errors decrease the expected performance and service life of pavements.

To cope with these types of failures techniques have been developed. One such technique is the modification of hot-mix asphalt (HMA) by the utilization of asphalt roofing shingle scrap. This technique can result in improved performance and service life of pavements.

Approximately 11 million tons of waste asphalt roofing shingles are generated in the US per year. Reroofing jobs account for 10 million tons, with another 1 million from manufacturing scrap. California is estimated to generate 1.2 million tons per year; of which 1.1 million are tear-offs from reroofing jobs [1]. Disposal of waste material is usually accomplished by transporting and depositing it in landfills. If a suitable means of reusing these materials can be found, then their environmental liability could be significantly reduced.

Since asphalt roofing shingles are composed of 30–35% relatively hard asphalt cement, 50–60% fine aggregate/mineral filler and 1–12% organic or inorganic fiber, an alternative to landfill deposition is to use the roofing

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waste in a related bituminous material. Such applications could include its use in granular base stabilization, patching materials or in HMA concrete [2].

The objectives of this study were to review the literature to determine the effects of the use of roofing shingles on the engineering properties of HMA and to conduct experiments in order to evaluate the use of roofing shingle waste from the manufacturing process and from reconstruction in HMA concrete mixtures.

2. Literature review

Researchers at the University of Nevada-Reno investigated the economic and technical aspects of using waste roofing for reconstruction in HMA. They concluded that the use of shingle waste resulted in a lower cost of paving material [3]. Paulsen et al. [4] stated that the use of roofing waste tended to increase the stiffness of the mixtures. This could be reasonably expected due to use of higher viscosity asphalt in the shingles along with the reinforcing effect of the fiber.

Information provided from Brock and Shaw [5] showed that if a contractor provided a mixture with 5% organic shingles, the HMA cost could be reduced by 2.79\$ per ton.

Newcomb et al. [6] conducted some experiments so as to evaluate the use of roofing shingle waste from the manufacturing process and from reroofing construction as additives in both dense-graded and stone mastic asphalt mixtures. The study concentrated on low temperature and permanent deformation characteristics of HMA mixtures manufactured with roofing wastes. Their study showed that

1. Manufactured shingle waste can be incorporated into dense-graded asphalt concrete.
2. The use of shingle waste can result in a reduction of optimum binder content.
3. The utilization of fiberglass manufactured shingle waste in HMA would not offer an advantage at low temperatures.
4. The addition of shingle to dense-graded mixtures improves the rutting resistance of the mixture.

Grzybowski [7] evaluated the use of recycled asphalt in dense-graded mixtures. The study concluded that the use of shingle waste would improve the rutting resistance of the mixture.

Ali et al. [8] studied the feasibility of using reclaimed roofing materials in HMA pavements. The results indicated that the use of shingles increased the stiffness of the mixtures. The addition of roofing shingles also resulted in a reduction in the additional asphalt cement (AC) required to produce an HMA mixture. Laboratory studies also indicated that incorporating shingle waste in

asphalt mixes tends to improve high temperature susceptibility and rutting resistance properties as well as fatigue life of pavements.

Foo et al. [9] prepared mixture designs of HMA mixtures with and without shingles. Their study showed that

1. The asphalt from the shingles causes a significant increase in the stiffness of the recycled asphalt binder, and in order to increase the performance grade (PG) of the recycled asphalt binder by one grade, 5% additional shingle is sufficient.
2. The use of shingles in HMA mixture improves the rutting resistance of the mix. However, the mix may have a lower fatigue resistance and also a lower low temperature cracking resistance. The use of appropriate softer neat asphalt improves the fatigue and low temperature performance of the mix.

3. Processing and engineering properties of roofing shingles

3.1. Processing

Asphalt roofing shingles undergo some processing before being used in HMA. These processes are shredding, screening, blending and watering.

Roofing shingle scrap used in HMA is typically shredded into pieces approximately 13 mm (1/2 in.) in size and smaller using a shingle shredding machine that consists of a rotary shredder or a high speed hammer mill. After this operation, shredded shingles are screened to the desired gradation and stockpiled. Experience indicates that the size of processed pieces should be no larger than approximately 13 mm to ensure complete digestion of the roofing shingle scrap and uniform incorporation into the HMA [10]. Scrap shingle greater than 13 mm in size does not readily disperse, functioning much like aggregate.

Processed roofing shingle material can harden during stockpiling, necessitating reprocessing and rescreening prior to introduction to the hot-mix plant. In order to mitigate this problem, processed roofing scrap may be blended with a carrier material such as sand or recycled asphalt to prevent the particles from sticking together.

A watering process is used to keep the roofing shingle material from agglomerating during processing. However, the application of water is not very desirable because the processed material becomes quite wet and must be dried prior to introduction into the HMA.

3.2. Engineering properties

Some of the properties of roofing shingles tabs are of particular interest when roofing shingles are used

in asphalt paving including asphalt cement content (ACC), asphalt hardness, aggregate content and gradation [10].

The composition of roofing shingle waste materials is complex, varying between product types and forms. They are generally composed of 30–40% air-blown asphalts; 50–60% inorganic mineral filler/granules which supplement the fine aggregate fraction of HMA; and 1–12% inorganic and/or organic fiber (fiberglass, cellulose, etc.) [7,10].

Accurate determination of the shingle scrap asphalt content and penetration is not possible using conventional recovery techniques because asphalt in shingle waste is much harder than that normally used in asphalt concrete paving mixtures. It also contains fibers which tend to stiffen asphalt concrete mixtures. Extended soaking periods are required to extract and determine the available asphalt.

4. Experimental

4.1. Materials

HMA mixtures were prepared with limestone aggregate from Torbali/Izmir quarry. Gradation chosen for this project is the wearing course Type 2 gradation of Turkish specifications. Table 1 summarizes the properties of the aggregate.

The properties of the AC are shown in Table 2. As seen from the Table, the AC used in this study is 60/70 penetration grade asphalt (ASTM D 946).

The roofing shingle waste was provided by BTM A.S, a local company in Izmir/Turkey. The properties of the shingle waste are given in Table 3.

4.2. Experimental programme

The plan of this study included the following steps:

1. Determine aggregate physical properties: This section includes sieve analysis (ASTM C 136); specific gravity of coarse aggregate (ASTM C 127), fine aggregate (ASTM C 128) and filler (ASTM D854); Los Angeles abrasion resistant test (ASTM C 131), flat and elongated

Table 2
Properties of asphalt cement

Properties	Specification used	
Source	Aliaga/Turkey	
Penetration grade	60/70	
Penetration at 25 °C	66	ASTM D 5
Specific gravity	1.029	ASTM D 70
Softening point (°C)	49	ASTM D 36
Loss on heating (%)	2	ASTM D 6
Flash point (°C)	296	ASTM D 92
Ductility at 5 cm/min	>100 cm	ASTM D 113
Viscosity at 135 °C	0.420 Pa s	ASTM D 4402
Viscosity at 165 °C	0.114 Pa s	ASTM D 4402

Table 1
Properties of aggregate

Test	Specification used	Actual value	Criteria
Gradation	ASTM C 136		
3/4 in.		100	100
1/2 in.		92	83–100
3/8 in.		80	70–90
No. 4		48	40–55
No. 10		32	25–38
No. 40		15	10–20
No. 80		10	6–15
No. 200		7.5	4–10
Specific gravity (coarse aggregate)	ASTM C 127		
Bulk		2.663	—
SSD		2.678	—
Apparent		2.705	—
Specific gravity (fine aggregate)	ASTM C 128		
Bulk		2.650	—
SSD		2.670	—
Apparent		2.703	—
Specific gravity (filler)		2.686	—
LA Abrasion (%)	ASTM C 131	21.5	Max. 35–45%
Flat and elongated particles (%)	ASTM D 4791	7.5	Max. 10%
Fine aggregate angularity	ASTM C 1252	42	Min. 40% for medium traffic level
	AFNOR P 18–564 (French specification)	36	Min. 35% for medium traffic level
Soundness	AASHTO T 104	1.2	Max. (10–20%)

Table 3
Properties of the shingle^a

Type of material	Value (%)
Asphalt (10/20)	32.5
Fiberglass (glass felt)	2.5
Filler (CaCO ₃)	30
Aggregate (Basalt)	35

^a Provided by BTM A.S./Izmir, Turkey.

particles test (ASTM D 4791), fine aggregate angularity test (ASTM C 1252, AFNOR P18-564), and soundness test (AASHTO T 104).

2. Determine the asphalt cement properties: This section includes specific gravity test (ASTM D 70), penetration test (at 25 °C) (ASTM D 5), softening point test (ASTM D 36), loss on heating test (ASTM D 6), flash point test (ASTM D 92), ductility test (ASTM D 113), and viscosity test (at 135 and 165 °C) (ASTM D 4402).

3. Perform Marshall method and determine optimum ACC: In determining the optimum ACC for a particular gradation of aggregates by Marshall method of mix design (ASTM D 1559), a series of test specimens are prepared for a range of different ACC so that the test data curves show a well defined optimum value.

Tests should be scheduled on the basis of 0.5% increment of asphalt content. Three test specimens are prepared for each ACC used in order to provide adequate data. Thus, a hot-mix design study using six different ACC will normally require 18 test specimens.

Before preparing mixtures, approximately 1150 g of the mix aggregates and the filler are taken and heated to a temperature of 175–190 °C. The bitumen is heated to temperature of 135–140 °C and the required quantity of the first trial percentage of bitumen (say 4% or 4.5% by weight of the aggregates) to the heated aggregates and thoroughly mixed at the desired temperature of 160–165 °C. The mix is placed in a preheated mould and compacted by a Marshall hammer with 75 blows (for wearing course) on either side at temperature of 138–149 °C. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5 ± 3 mm. ($2^{1/2}$ in.) (corrections can be made for different sample thicknesses) [11].

The Marshall stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature (60 °C) placed in the special test head and the load is applied at a constant stain (2 in. per minute). While the stability test is in progress, the dial gauge is used to measure the vertical deformation of the specimen; the deformation read at the load failure point is expressed in units of 0.25 mm and is called the Marshall flow value of the specimen [11].

The test is repeated for other specimens of each ACC and an average value for each ACC is taken. As the specific gravity of aggregates and asphalt, bulk density, stability and flow value of the specimen are known, the following graphical curves can then be plotted:

- Corrected Marshall stability versus asphalt content.
- Marshall flow versus asphalt content.
- Percentage of void (Vh) in the total mix versus asphalt content.
- Unit weight or bulk specific gravity (Dp) versus asphalt content.
- Percentage of void filled with asphalt (VFA) versus asphalt content.
- Percentage of void in mineral aggregate (VMA) versus asphalt content.

To determine the optimum asphalt content for the mix design, one takes the average value of the following three asphalt contents found from the graphs obtained in the previous steps.

- Asphalt content corresponding to maximum stability.
- Asphalt content corresponding to maximum bulk specific gravity (Dp).
- Asphalt content corresponding to the median of designed limits of percent air voids (Vh) in the total mix (i.e., 4%).

By referring to the curves, stability value, flow value and VFA at the optimum asphalt content are determined and each of these values is checked with Marshall mix design specification values.

Mixes with very high stability value and low flow value are not desirable as the pavements constructed with such mixes are likely to develop cracks due to heavy moving loads.

4. Prepare HMA mixtures that contain 1–5% roofing shingle as well as control mixtures.

5. Determine the engineering properties of HMA mixtures with and without shingles by conducting Marshall stability test.

6. Draw conclusions based on the results.

7. Conduct rutting tests on the mixtures that contains the optimum single content addition which gives the best value in terms of Marshall stability.

The purpose of the tests performed with the LCPC (Laboratoire Central des Pont et Chaussées) Pavement Rutting Tester (French type traffic simulation equipment) is to characterize the resistance to rutting of the asphaltic materials in conditions which are similar to prevailing conditions on roads.

8. Make overall conclusions and provide recommendations on the use of shingles and on further research.

4.3. Test results and discussion

4.3.1. Marshall mix design

After determining the properties of the materials used in this project, the Marshall stability test was conducted on the specimens that contain different asphalt content in order to determine the optimum asphalt content. The result of Marshall mix design is presented in Table 4 and Fig. 1.

The optimum asphalt content that corresponds to 4% air voids was found as 5%. The calculated and measured mixture properties and their comparison according to design criteria are given in Table 5.

As seen from Table 5, all of the properties of mixture are within specification limits for wearing course.

After determining the design asphalt content (5%), in order to evaluate the effect of shingle waste addition on the properties of conventional (unmodified-neat) HMA, the Marshall stability test was conducted on the mixtures that contain no shingle (control mixes) and on the mixtures that contains 1–5% of roofing shingle waste.

The reason for using 5% as the maximum value of shingle waste addition is that above 5% shingle waste addition, the HMA mixture will exceed the binder tolerance which is $\pm 0.3\%$. Information on materials used to procedure HMA mixtures is given in Table 6.

The Marshall stability test results of the mixtures that contain shingle waste and control samples; and the change of Marshall stability values based on different shingle waste addition are given in Table 7 and Fig. 2, respectively.

From Fig. 2, it can be seen that Marshall stability values increase up to 1% shingle waste addition. However, as the shingle waste addition increases, the stability values decrease. Therefore, it can be concluded that stability values increases of up to 1% shingle waste addition give the best results in terms of stability. It should be noted that the level of air voids decreases with shingle waste addition (Table 7). Based on the past research [6], it was found out that mixtures containing shingle waste were easier to compact then conventional (unmodified) mixtures. Therefore, it can be concluded that a very low air void level in mixtures may be due to the shingle waste addition.

Researchers indicated that the use of roofing shingle waste can result in a reduction of optimum asphalt content [12,13]. Based on past studies, in order to evaluate the utilization of shingle waste on the reduction of optimum asphalt content, 5% asphalt content was decreased by 0.5% and 1%. The Marshall stability test was conducted on the specimens that were prepared with these two asphalt contents (4.5% and 4%) and 1% roofing shingle waste. Results are presented in Table 8.

Table 4
Marshall design

Number of blow : 75			Marshall design										Specific gravity of bitumen				1,029									
													Bulk specific gravity of mix				2,658									
													Effective specific gravity of mix				2,687									
Specimen No	Bitumen %		Weight in air (gr)		Saturated surface dry weight (gr)	Volume	Bulk specific gravity	Max theoretical specific gravity	Voids %	VMA %	VFA %	Specimen height (mm)				Stability (kg)	Correlation factors	Corr. stability (kg)	Flow (mm)							
	W _b	W _s	A	C								B	V	D _B	D _T					V _b	VMA	V _f	1	2	3	Avr.
1	4.0	3.85	1193	690	1196	506	2,358	2,530	6,879	14,765	53,414	64.2	64.0	64.1	64.1	958	0.985	944	2.5							
2			1192	688	1194	506	2,356					64.0	64.2	64.1	64.1	1053	0.985	1037	2.3							
3			1194	690	1197	507	2,355					64.0	64.3	64.1	64.1	989	0.985	974	2.5							
																			985	2.43						
4	4.5	4.31	1198	693	1199	506	2,368	2,513	5,577	14,584	61,759	63.6	64.0	63.8	63.8	1070	0.992	1061	2.5							
5			1197	694	1198	504	2,375					63.7	63.8	63.7	63.7	1006	0.995	1001	2.8							
6			1197	694	1198	504	2,375					63.6	63.6	63.6	63.6	1026	0.998	1024	2.5							
																			1029	2.60						
7	5.0	4.76	1205	702	1206	504	2,391	2,496	4,136	14,282	71,041	63.5	63.3	63.4	63.4	1114	1.003	1117	2.8							
8			1203	701	1204	503	2,392					63.5	63.1	61.8	62.8	1000	1.006	1006	2.8							
9			1202	701	1203	502	2,394					63.0	62.9	62.2	62.7	1023	1.013	1036	2.5							
																			1036	2.70						
10	5.5	5.21	1209	707	1210	503	2,404	2,479	3,055	14,305	78,641	63.4	62.6	61.0	62.3	1032	1.011	1043	2.8							
11			1211	708	1212	504	2,403					62.5	63.1	61.6	62.4	1016	1.018	1034	2.8							
12			1211	708	1212	504	2,403					62.6	62.8	61.7	62.4	1006	1.021	1027	2.5							
																			1034	2.70						
13	6.0	5.66	1210	707	1211	504	2,401	2,462	2,513	14,799	83,017	63.7	63.2	61.7	62.9	972	1.003	975	2.8							
14			1212	708	1213	505	2,400					63.4	63.8	61.3	62.8	921	1.000	921	2.8							
15			1210	707	1211	504	2,401					63.2	63.5	61.3	62.7	915	1.011	925	2.8							
																			940	2.80						
16	6.5	6.10	1210	706	1211	505	2,396	2,446	2,021	15,324	86,811	63.7	63.2	61.7	62.9	878	1.003	881	2.8							
17			1216	710	1217	507	2,398					63.4	63.8	61.3	62.8	857	0.998	855	2.8							
18			1215	709	1216	507	2,396					63.2	63.5	61.3	62.7	867	1.066	924	3.0							
																			887	2.87						
Specific gravity of bitumen (Gb)			1,029				Coarse aggregate % (K%)					46.0				Specific gravity of coarse agg. (Gk)					2,663					
Penetration			60/70				Fine aggregate % (I%)					49.1				Specific gravity of fine agg. (Gi)					2,650					
Bitumen abs. of aggregate (Pba)			0.418				Filler % (F%)					4.9				Specific gravity of filler (Gf)					2,686					
Effective sp. grav. of mix (Ge)			2,687				Bulk specific gravity of mix (Gsb)					2,658				Aggregate (gr.)					1150					

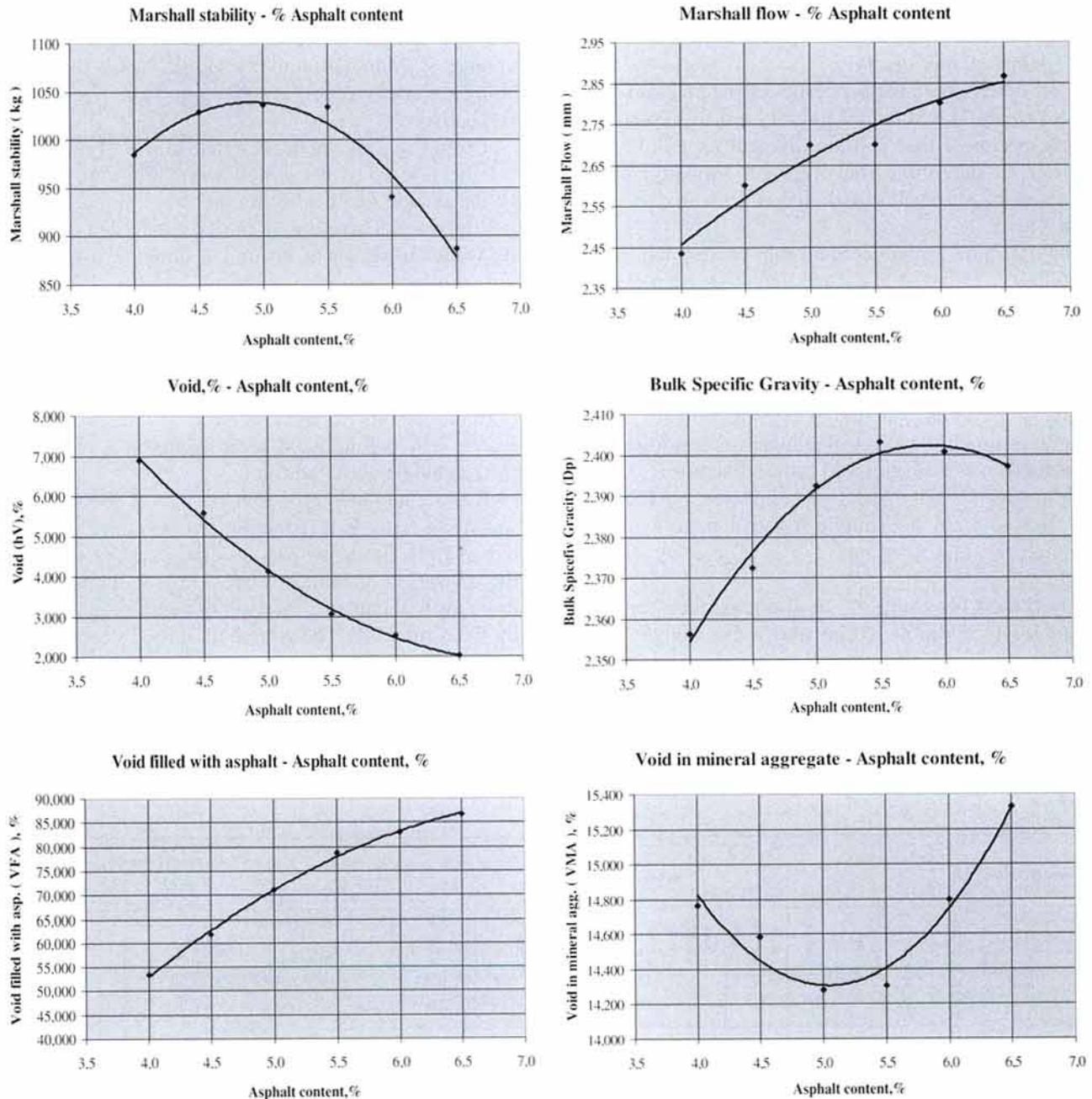


Fig. 1. Marshall mix design values.

Results showed that for both of the specimens compacted with 4.5% and 4% binder content together with 1% shingle waste, the Marshall stability values increased when compared to the control samples (compacted with optimum binder content of 5%). Among these, the sample prepared with 4.5% binder content gave the best value in terms of stability. Therefore, it can be concluded that the utilization of roofing shingle waste in HMA results in a reduction in the optimum asphalt content. The 0.5% reduction in the optimum binder content can result in significant reduction in the cost of HMA.

It is interesting to note that the level of air voids is higher when compared to the control samples. It may be due to the reduction of asphalt cement content. However, the level of air void that corresponds with the mixture that contains 4.5% asphalt stays within the specification limits (3–5%).

4.3.2. Rutting test

When taking 1% roofing shingle waste addition into account, rutting tests were performed on both of the specimens compacted without shingle and 1% shingle waste addition by LCPC pavement rutting tester.

Table 5
Properties of the mix at 5% asphalt content and design criteria for wearing course

Type of material	Value	Design criteria for surface course (heavy traffic condition)	
		Minimum	Maximum
Marshall stability	1036	900	–
Bulk specific gravity (Gsb)	2.658	–	–
Flow (mm)	2.70	2	4
Voids in total mix	4.136	3	5
Aggregate voids filled with asphalt (VFA)	71.041	65	85
Voids in mineral aggregate (VMA) ^a	14.282	14	–
Blows	75	75	–

^a Based on normal maximum aggregate size.

Table 6
Material information for Marshall design

	No Shingle	1% Shingle	2% Shingle	3% Shingle	4% Shingle	5% Shingle
Aggregate (gr)	1150	1137.925	1128.85	1113.775	1101.7	1089.625
Binder (gr) (5% of mixture weight)	57.5	57.5	57.5	57.5	57.5	57.5
Shingle (gr)	–	12.075	24.15	36.225	48.3	60.375
Mixture (gr)	1207.5	1207.5	1207.5	1207.5	1207.5	1207.5
Binder tolerance (±3%)	–	0.05%	0.09%	0.16%	0.22%	0.26%

The test was performed on asphalt concrete slabs (500 × 180 × 100 mm) at 60 °C. The compaction was performed by “LCPC Plate Compactor” for all the

mix specimens. The specimens were set at room temperature for 12 h before being tested. The applied load on each pneumatic wheel (400 mm diameter by 90 mm

Table 7
Marshall stability test results based on shingle waste addition

Number of blow : 75				Marshall design based on shingle waste addition										Specific gravity of bitumen				1,029	
														Bulk specific gravity of mix				2,658	
														Effective specific gravity of mix				2,687	
Shingle	Bitumen %		Weight in air (gr)	Weight in air (gr)	Saturated surface dry weight (gr)	Volume	Bulk specific gravity	Max teorical specific gravity	Voids %	VMA %	VFA %	Specimen height (mm)				Stability (kg)	Correlation factors	Corr. stability (kg)	Flow (mm)
	W_u	W_b	A	C	B	V	D_p	D_f	V_b	VMA	V_f	1	2	3	Avr.				
0%	5,0	4,76	1205	702	1206	504	2,391	2,496	4,136	14,282	71,041	63,5	63,3	63,4	63,4	1114	1,003	1117	2,8
			1203	701	1204	503	2,392					63,5	63,1	61,8	62,8	1000	1,006	1006	2,8
			1202	701	1203	502	2,394					63,0	62,9	62,2	62,7	1023	1,013	1036	2,5
																	1053	2,70	
1%	5,0	4,76	1184	703	1185	482	2,455	2,496	1,729	12,130	85,743	60,0	60,0	63,8	61,3	1123	1,099	1234	2,7
			1181	700	1181	481	2,454					60,0	60,0	63,7	61,2	1191	1,097	1307	4,1
			1176	696	1177	481	2,447					60,0	60,0	63,6	61,2	1026	1,020	1047	3,0
																	1196	3,27	
2%	5,0	4,76	1203	711	1185	474	2,538	2,496	2,233	12,580	82,252	61,3	61,2	63,4	62,0	1024	1,094	1120	1,9
			1185	697	1211	514	2,304					60,3	60,3	60,3	60,3	1093	1,094	1196	3,9
			1210	715	1203	489	2,477					61,6	61,6	61,6	61,6	1040	1,094	1138	1,3
																	1138	2,37	
3%	5,0	4,76	1194	706	1194	488	2,446	2,496	2,537	12,852	80,259	61,0	61,0	61,0	61,0	925	1,096	1014	4,3
			1210	714	1211	497	2,435					62,1	61,9	61,6	61,9	938	1,093	1025	2,6
			1199	703	1199	496	2,416					60,8	60,8	61,7	61,1	972	1,097	1066	2,0
																	1025	2,97	
4%	5,0	4,76	1187	701	1188	487	2,439	2,496	2,647	12,950	79,562	60,8	60,5	61,7	61,0	898	1,097	985	2,6
			1200	704	1201	497	2,417					61,6	61,3	61,3	61,4	900	1,094	985	3,2
			1192	703	1193	490	2,433					60,8	61,0	61,3	61,0	853	1,096	935	4,0
																	968	3,27	
5%	5,0	4,76	1161	680	1161	482	2,410	2,496	3,098	13,353	76,802	59,4	59,9	61,7	60,3	778	1,099	855	3,2
			1211	711	1211	501	2,419					62,0	62,8	61,3	62,0	783	1,093	856	3,9
			1171	689	1171	483	2,426					60,0	60,0	61,3	60,4	828	1,099	910	2,2
																	874	3,10	
Specific gravity of bitumen (Gb)				1,029		Coarse aggregate % (K%)				46,0		Specific gravity of coarse agg. (Gk)				2,663			
Penetration				60/70		Fine aggregate % (I%)				49,1		Specific gravity of fine agg. (Gi)				2,650			
Bitumen abs. of aggregate (Pba)				0,418		Filler % (F%)				4,9		Specific gravity of filler (Gf)				2,686			
Effective sp. grav. of mix (Gef)				2,687		Bulk specific gravity of mix (Gsb)				2,658		Aggregate (gr.)				1150			

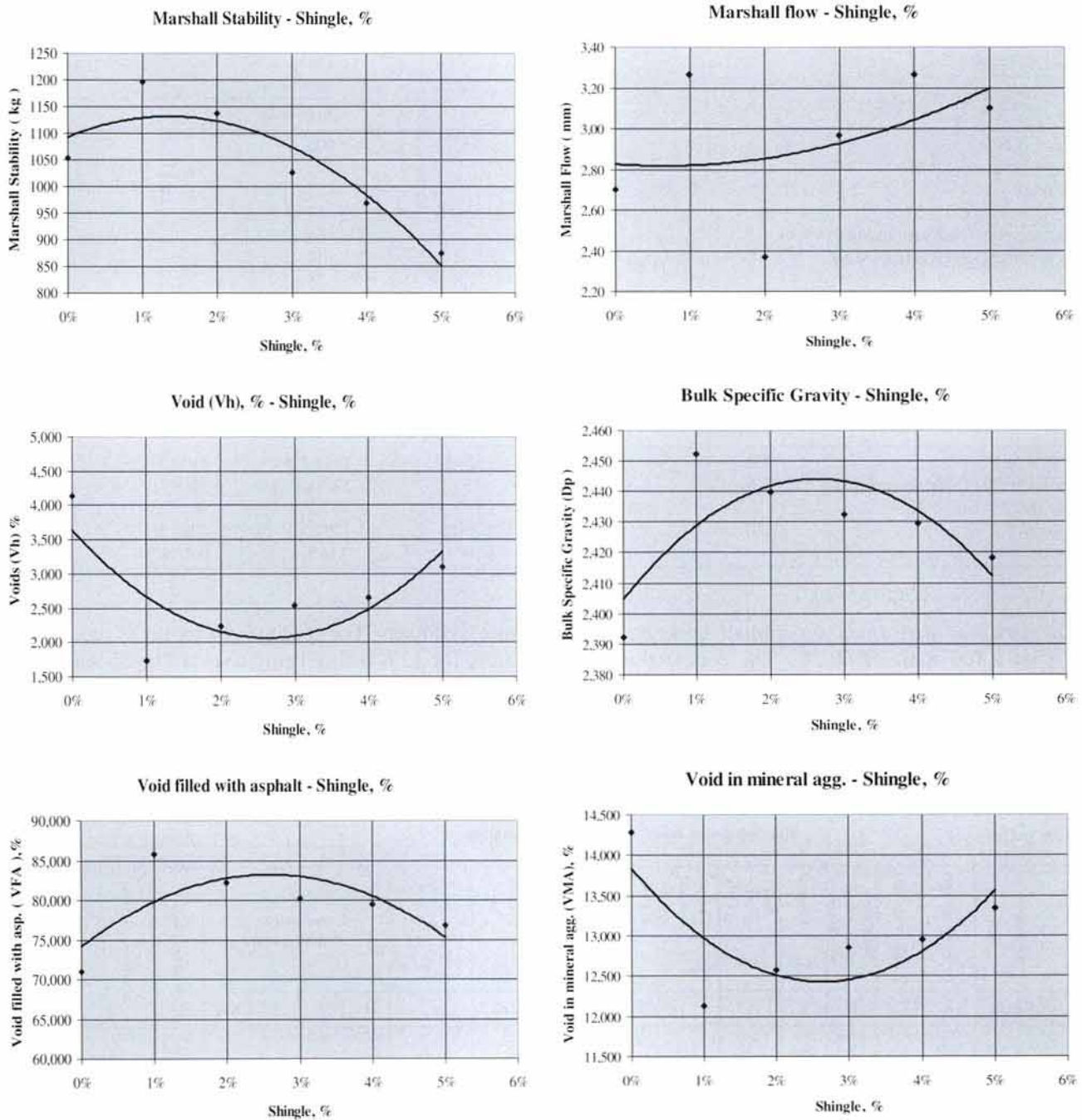


Fig. 2. Marshall mix design values based on shingle content.

wide) was 5000 N during the test that provides 600 kPa flexible wheel pressures.

A pre-test loading condition was applied prior to determination measurement; specimens were subjected to 1000 cycles without preheating (1 cycle = 1 travel and return of the tyre). Deterioration measures were then carried out after 100, 300, 1000, 3000, 10000, 30000, 50000 cycles. The test was stopped when the average recorded rut depth after a series of measures was higher than 10% and that the previous results

anticipated a rut depth of more than 15% at the following step.

The rut depth was obtained by calculating the average of the 15 measurements located under the wheel movement between the origin and the considered cycles. It is expressed in percentage of the thickness of the original specimen.

$$Pi(\%) = 100 \left(\frac{\sum j(m_{ij} - m_{oj})}{(15 \times E)} \right) \quad (1)$$

Table 8
Marshall stability test results based on optimum binder content reduction

Number of blow : 75			Marshall design based on opt. binder content reduction										Specific gravity of bitumen				1,029		
													Bulk specific gravity of mix				2,658		
													Effective specific gravity of mix				2,687		
Shingle	Bitumen %		Weight in air (gr)	Weight in air (gr)	Saturated surface dry weight (gr)	Volume	Bulk specific gravity	Max theoretical specific gravity	Voids %	VMA %	VFA %	Specimen height (mm)				Stability (kg)	Correlation factors	Corr. stability (kg)	Flow (mm)
	W_a	W_b	A	C	B	V	D_p	D_T	V_b	VMA	V_f	1	2	3	Avr.				
0%	5,0	4,76	1205	702	1206	504	2,391	2,496	4,136	14,282	71,041	63,5	63,3	63,4	63,4	1114	1,003	1117	2,8
			1203	701	1204	503	2,392					63,5	63,1	61,8	62,8	1000	1,006	1006	2,8
			1202	701	1203	502	2,394					63,0	62,9	62,2	62,7	1023	1,013	1036	2,5
							2,392									1053	2,70		
1%	4,5	4,31	1180	692	1181	489	2,412	2,513	4,761	13,846	65,613	60,0	60,3	60,2	60,1	1241	1,099	1364	3,2
			1187	695	1189	494	2,403					61,0	60,8	60,8	60,9	1227	1,097	1346	2,8
			1175	681	1178	497	2,364					61,0	60,8	60,8	60,9	1161	1,097	1274	2,7
							2,393									1328	2,90		
1%	4,0	3,85	1195	693	1197	504	2,370	2,530	5,954	13,919	57,225	62,4	62,2	62,5	62,4	1102	1,092	1203	1,8
			1191	697	1192	495	2,406					61,5	61,6	61,8	61,6	1208	1,094	1322	1,6
			1199	694	1201	507,5	2,363					62,3	62,3	62,5	62,3	1149	1,092	1255	1,8
							2,380									1260	1,73		
Specific gravity of bitumen (Gb)			1,029			Coarse aggregate % (K%)					46,0		Specific gravity of coarse agg. (Gk)			2,663			
Penetration			60/70			Fine aggregate % (I%)					49,1		Specific gravity of fine agg. (Gi)			2,650			
Bitumen abs. of aggregate (Pba)			0,418			Filler % (F%)					4,9		Specific gravity of filler (Gf)			2,686			
Effective sp. grav. of mix (Gef)			2,687			Bulk specific gravity of mix (Gsb)					2,658		Aggregate (gr.)			1150			

where J is the number of measured points; m_{ij} the measure of a certain cycle (average of 15 points); m_{0j} the measure of after 1000 cold cycles (average of 15 points); and E is the depth of the sample.

The results of the rutting tests are given in Fig. 3.

It should be noted that at the end of 10000 wheel load cycles, the rut depth for the mixture prepared with 1% shingle waste was about 4 mm, while the rut depth

for the mixture prepared without shingle was about 16 mm. In addition, the rut depth value after the 30000 cycles (7.5 mm) of the mixture containing shingle is under the specification limit (10 mm).

This results show that the addition of roofing shingle waste improves the rutting resistance of the mixture considerably.

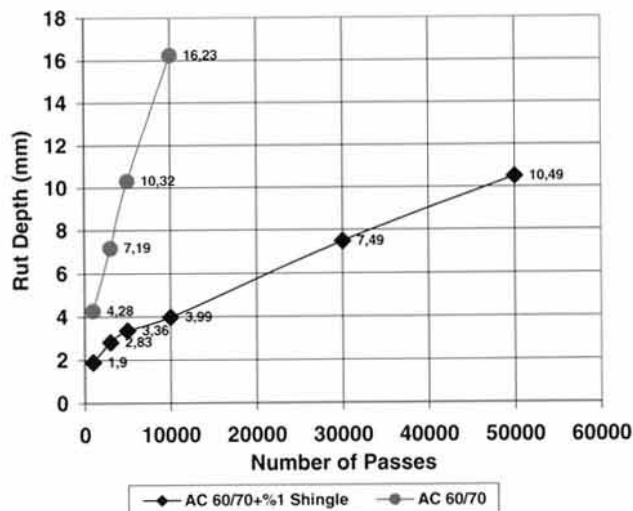


Fig. 3. Rutting test results.

5. Conclusions and recommendations

The objectives of this study were to firstly evaluate the utilization of shingle waste addition on the performance of HMA in terms of stability and resistance to permanent deformation and secondly to determine the addition on the reduction of optimum asphalt content.

The literature review showed that shingle waste addition increases the stiffness of asphalt concrete paving mixtures. In cold climate conditions, this situation can lead to problems with thermal cracking. However, this project was performed in the hot climatic conditions in Turkey. Therefore, rutting properties of asphalt concrete that contains shingle waste are the main focus of this experimental investigation rather than cold temperature properties of asphalt pavement.

Based on the data presented in this paper, the following conclusions can be drawn:

1. Manufactured roofing waste shingles can be incorporated into the dense graded mixtures and the addition of these waste shingles can produce properties comparable to conventional (unmodified) HMA mixtures.
2. The effect of shingle waste addition on the properties of HMA (containing 1–5% shingle waste) was evaluated by Marshall mix design (Table 7). From Fig. 2, it is concluded that Marshall stability values increase up to 1% shingle waste addition. However, as the shingle waste addition increases, the stability values decrease. Therefore, it can be concluded that 1% shingle waste addition gives the best results in terms of stability and this content is recorded as optimum shingle content addition.
3. The stability values of the mixtures that contain 3% and 4% shingle waste are somewhat lower than the control samples. However, the stability values of these mixtures are still higher than the minimum value of the specification criteria which is 900 kg. The addition of shingle waste above 5% may cause some problems; the binder tolerance of $\pm 0.3\%$ will be exceeded and also some problem may arise during application in batch plants if feeding is done manually.
4. Although shingle waste addition of more than 2% decreases the stability values compared to control samples, flow values do not significantly change and all flow values stay within the specifications (Table 5).
5. The air void level of mixtures containing shingles waste decreases because mixtures containing shingle waste were easier to compact than conventional mixtures. This is also due to the composition of the shingle, which contains 30% filler.
6. In order to evaluate the utilization of shingle waste on the reduction of the optimum asphalt content, the Marshall test was conducted on the specimens that were prepared by 4.5% and 4% asphalt content together with 1% shingle waste. The results showed that the reduction of the optimum bitumen binder content by 0.5% in the HMA that contains 1% roofing shingle waste significantly increases the stability values of the mixture that contains the same percentage of shingle waste (Table 8). This is another benefit of using a roofing shingle waste in HMA from the performance and economic point of view.
7. The rutting test was performed on the specimens that contain 1% shingle waste by LCPC pavement rutting tester. Test results (Fig. 3) show that the addition of shingle waste improves the rut resistance of the mixture significantly.
8. The literature review indicated that fiberglass shingle waste does not affect the low temperature properties of the mixture. However, it may improve the resist-

ance to fatigue cracking of the asphalt concrete pavement. This study could be improved by conducting further research in order to evaluate the fatigue cracking properties of HMA.

Based on the above results, the advantages of the utilization of shingle waste in HMA are listed below:

1. A reduction in the cost of shingle waste disposed.
2. An environmental benefit resulting from the conservation of landfill space.
3. A reduced cost in the production of HMA concrete resulting from reduction in the use of new material.
4. An improved resistance to pavement cracking due to reinforcement provided by the fibers in shingle.
5. An improvement to pavement rutting due to a combination of the fibers and harder asphalt (10/20 penetration at 25 °C) used in the shingle.

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